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EFFECT OF CAVITATION EROSION OVER A NI-AL-BRONZE PROPELLER

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Abstract: Commercial vessels with large deadweight capacity engaged in international voyages are generally powered by a single propeller. Hence, because the responsibility for developing the thrust force lays upon a single thrust component and redundancy cannot be ensured, a comprehensive evaluation for the operational conditions is to be carried out, as the propeller is closely related with the hydrodynamic seaworthiness of the vessel, which should precede any propulsion analysis, [1-2]. Despite the proven reliability of the nickel–aluminium-bronze alloy (NAB hereafter) used in its manufacturing, a marine propellers exposed to the risk of extended cavitation, the propeller is prone to localised wear and surface degradation. This is the reason of the present research aimed at is addressing the problematics of cavitation erosion of NAB propellers by employment of CFD investigation instruments. Cavitation occurrence is emphasised on a simplified three blades propeller together with hydrodynamic characteristics evaluation. Hence, the initiation of the cavitation on the blades surfaces is described together with a brief introduction of the most commonly used mitigation and recondition techniques of cavitation affected areas of propeller blades through modern methodologies.
Keyword: Cavitation erosion, CFD, NAB, propeller wear

1. INTRODUCTION

Throughout the International Maritime Organization (IMO) fundamental principles a key role is to perpetuate technical advancement of the components engaged in fuel efficiency of a maritime vessel, [1]. To accomplish that, a comprehensive analysis should focus not only on the propulsive equipment performances but also on a hull hydrodynamics introspection, [2-3].

It was Ene et al., who have proven in [4] that the key parameters of propulsion descriptors are the thrust force and the torque moment, as functions dependant of a series of parameters such as propeller diameter, blades number, hull interference thrust advance, pitch and propeller rotational speed. Although in its early design stage the propeller might seem to develop the necessary hydrodynamic performances, during the vessel operation, its overall efficiency becomes highly dependent on maintenance factors, such as close up examination for potential damage identification, periodic cleaning and polishing, [1].

A significant damage source which needs to be assessed is the cavitation erosion. The phenomenon of cavitation refers to phase discontinuities occurrence throughout the fluid flow, generated by pressure drops on the propeller blades. The unwanted influence of cavitation is not only affecting the efficiency of the propeller through a thrust breakdown, but also by the induced vibrations on the superstructure accommodation area which is usually positioned in the aft part of the ship.

It has already been proven that the cavitation risk can be avoided either by an efficient geometry design of the propeller through a proper design sustained either by comprehensive experimental tests performed in cavitation tunnels, or by numerical simulations of the local flow features by using the CFD techniques [5-6]. Under such circumstances, the design criteria of the propeller had to be addressed in the past years, such as the permanent challenges of increasing the propulsion efficiency be met.

While in the 20th century cavitation occurrence was avoided by increasing the blade area under the cost of reducing the revolution rate, the pursuit of keeping a reasonable cost imposed by the ship shareholders led to a limitation of the available measures for avoiding the cavitation occurrence. In such a context, it became commonly accepted to tolerate a certain level of cavitation on the propeller blades and hub within a strictly controlled level of noise on board, limited by international conventions, [6].

On the other hand, although the marine propeller is commonly manufactured from a complex alloy of nickel aluminium and bronze with proven good resistance at corrosion and erosion properties, once the cavitation phenomenon is occurring into a fluid containing erosive

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particles, the synergistic effect of the cavitation on a surface may exceed the resistance threshold of the NAB alloy and the surface degradation is unavoidably initiated.

As mentioned above, analysing the behaviour of a propeller working in a cavitation regime, experimental tests on scaled propeller models in cavitation tunnels might be a proper choice in spite of their high costs. On the contrary, in such cases numerical predictions can be used to get accurate overall images of cavitation erosion areas at considerable lower costs, [7-8].

In response to the challenges of experimental cavitation assessment, a thorough instrument should be represented by a comprehensive numerical investigation through the computational fluid dynamics. Commonly known as an instrument highly dependent on the computational processing power, satisfactory outcomes may be available through the numerical solution of the Reynolds averaged Navier-Stokes (RANS) equations. Due to its capacity for using the averaging the turbulence close-up details, the methodology is decreasing the necessary CPU and computation time, [6].

2. MILESTONES OF THE CFD SETUP

Aimed at having a better description not only of the hydrodynamic performances of the propeller, but also of an accurate prediction of the cavitation mechanism, i.e. inception, development and extension, a CFD technique is proposed in the followings. A three-bladed propeller model of the DTMB 5415 ship is chosen to fit the purpose. The reason for choosing a 3 blades propeller was given by the limited computational resources, which eventually required a reasonable number of the discretisation cells.

The numerical simulation employs the ISIS-CFD solver of the Numeca Fine Marine software package. The very powerful numerical platform is regarded as one of the most reliable instruments for CFD analysis since it can solve the flow features by integrating the unsteady viscous free-surface flow equations accomplished by a wide variety of turbulence models. The partial differential equation set is iteratively solved within a given margin for the numerical errors. A sufficiently small step time is imposed such that the Courant number be below the unity. Meshing is performed such that a proper clustering be achieved on both leading and trailing edges, where the gradients of fluid pressure and velocity are expected to be significant. Consequently, a high discretization is also done in the intersection area of the boss with the blades, where violent separations are expected to develop. Due to the viscous friction, the speed drops to zero inside the boundary layer. This phenomenon does not occur linearly, but being described by a given low that defines the geometry of the velocity defect. The final mesh is depicted in Figure 1.

Table 1. Propeller particularities

Propeller diameter [m]	0.3
Advance speed [m/s]	3.0
Revolution rate [rpm]	1000

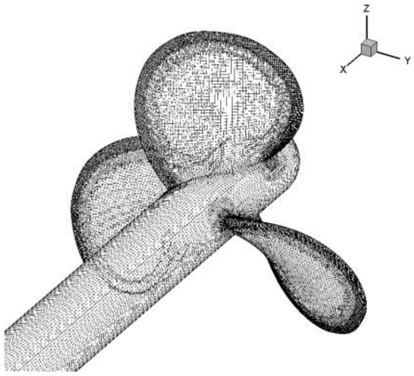

Figure 1 Isometric view of the geometry mesh

3. RESULTS AND DISCUTIONS

Three different simulations were performed for different revolution rates, under the hypothesis of constant axial flow speed. The advance coefficient defined as $J = v/nD$, where v is the advance speed, n is the propeller revolution rate and D is the propeller diameter, was calculated for each case, as tabulated in Table 2.

Table 2. Advance ratio coefficient values

Simulation	*n* [rpm]	*J*
1	900	0.666
2	1000	0.6
3	1100	0.545

Figures 2 (a) to (c) show not only a progressive increment of the pressure values, but also a decrease of the advance coefficient from 0.666 to 0.545. Obviously, the pressure gradients on the regions behind the leading edges are extending to the rest of the blade surface depending to the rotation increment from 900 rpm to 110 rpm, a fact that is confirmed by the physics. An increase of the loading for the blades is seen with the decrease of

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the advance coefficient, when the propeller is not heavy loaded. On the other hand, Figure 2 (d)…(f) clearly shows a pressure drop on the suction side of the running edge, marked with blue. Hence, the pressure difference between the suction side and the pressure side of the blades increases with the augmentation of the rotation rate, a fact that set the pace for cavitation initiation.

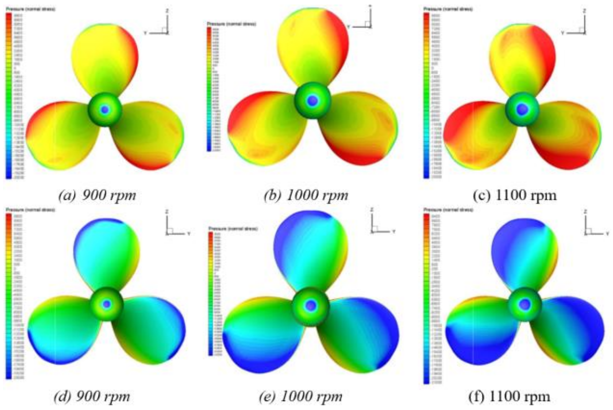

Figure 2 Pressure distribution on the pressure side (a) to (c) and on the suction side (d) to (f)

Figure 3 bears out the second invariant of the velocity gradient coloured in terms of pressure, Figure (a) to (c) and helicity, Figure (d) to (f), respectively. Vortices released by the blade tips unveil a well-defined helical structure growing up on the axial direction, then being eventually washed down in the stream. The increase of the revolution rate from 900 rpm to 1100 rpm brings out the slight decrease of the vortices pitch, as expected. Worth mentioning that a significant hub vortex develops axially behind the hub which coexists with the tip vortices and finally merge to weaken each other at the downstream.

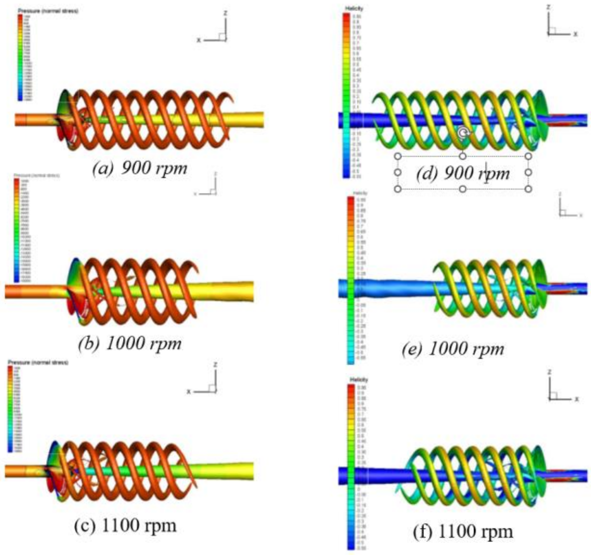

Figure 3 Pressure distribution considering second invariant (a) to (c) and helicity values (d) to (f)

Figure 4 depicts the main turbulent flow parameters drawn in the propeller wake for the three advance ratio coefficients considered in here. In spite of a rather poor discretization of the fluid domain behind the propeller, one may see the progressively decrease of the energy determined by the viscous dissipation, a fact that will further influence the overall propeller hydrodynamic performances.

After completing the numerical analyses, the thrust T, and the torque Q, produced by the propeller, were calculated in Table 3 and used to get the thrust and torque diagram, using KT and KQ coefficients, according to same advance ratio, see Figure 5. Because the two propellers of the ship rotate each in the other side, torque values may have negative values, depending the board where is mounted. For the sake of a proper evaluation, KQ values are introduced with their positive values.

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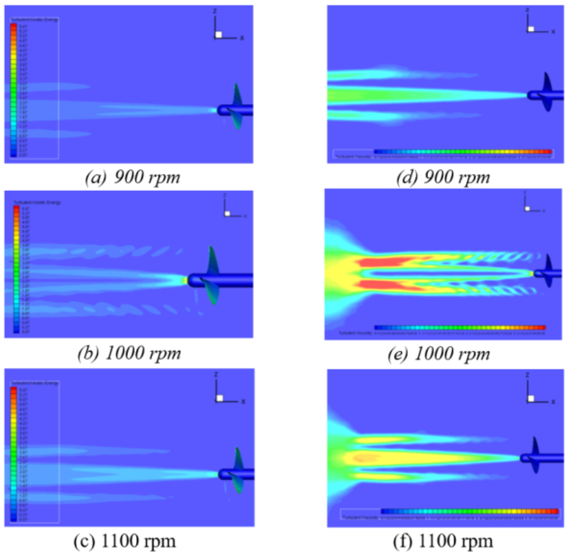

Figure 4 Turbulent kinetic energy (a) to (c) and turbulent viscosity (d) to (f)

Table 3. Thrust and torque values and coefficients

n [rpm]	*J*	*T* [N]	*Q* [Nm]	*KT*	*KQ*
900	0.666	428.6	-23.865	0.229	-0.042
1000	0.6	600.57	-32.335	0.26	-0.046
1100	0.545	792.89	-41.916	0.284	-0.05

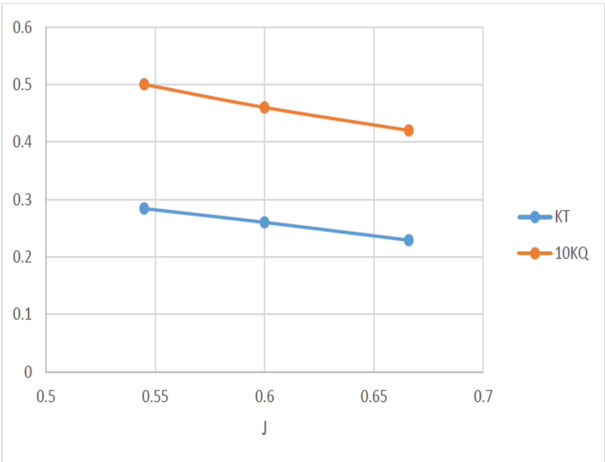

Figure 5 KT and KQ variation with the advance coefficient

As shown in Table 3, an increase of the revolution rate of the propeller, leads to higher values for the thrust and torque of the propeller, but under an unavoidable increment of the pressure fluctuation on the blade.

4. MITIGATION TECHNIQUES AND CONCLUDING REMARKS

The CFD simulation was performed with the aim of highlighting cavitation formation and occurrence, and it depicted how the vortices are initiated and developed. However, the context in modifying for the situation where cavitation erosion is observed in real operational conditions. Although it is not a common situation, the full scale propeller can suffer from cavitation erosion and its effects might be identified during periodical maintenance at the dry docking. In this case, the available time frame to implement a repair methodology and mitigation techniques it is very limited. Even so, measures are to be taken firstly to recondition the cavitation affected surfaces and furthermore, to optimise the cavitation resistance of the propeller alloy for the future.

For complex alloys such as the NAB from the marine propeller, repair techniques are a double challenge. On one side, depending on the affected area of the propeller, the repair itself might be prohibited, as regulated by IACS UR W24, and detailed more in other paper of the author, [1]. On the other side, the metallurgical structure and the high thermal conductivity of the NAB makes the alloy to be susceptible to cracking, residual stress between the grains and phases imbalances. Even so, it has been reported satisfactory repair of bronze alloy from the marine propeller with implementation of the emerging technology of laser cladding.

Tang et al. [9] obtained defect free laser cladding deposition on manganese nickel aluminium bronze propeller, with continuous laser methodology. Their technique revealed not only the possibility to rebuild the affected propeller, but also to expand the cavitation erosion resistance of the alloy up to almost 30 times more than the original material. Good outcome from laser cladding registered also Iatan et al. [10] by identification of the optimal parameters for laser cladding of a NAB substrate from a marine propeller with a pulsed laser. The study showed increasing the micro hardness and corrosion resistance of the original substrate, with the inherent asset of obtaining a defect free coating.

The present study describes through CFD instruments how cavitation occurs and grows on a marine propeller, pointing out on how the phenomenon can be analysed and limited at an early design stage. Furthermore, modern laser repair and material optimisation methodologies are introduced as a response to the situation where cavitation erosion became a consistent and real problem for vessel in operation.

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